Defense Technical Information Center Compilation Part Notice

ADP012415

TITLE: Thermal Protection Against Hot Steam Stress

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

This paper is part of the following report:

TITLE: Blowing Hot and Cold: Protecting Against Climatic Extremes [Souffler le chaud et le froid: comment se proteger contre les conditions climstiques extremes]

To order the complete compilation report, use: ADA403853

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP012406 thru ADP012451

Thermal Protection Against Hot Steam Stress

PhD. Anne-Virginie Desruelle, Tech. Bruno Schmid, Col. Alain Montmayeur
Institut de Médecine Navale du Service de Santé des Armées
BP 610
F-83800 Toulon Naval
France

Summary
In order to answer to the needs of the French Navy, the thermal protective capacities of textile samples and protective garments are assessed under hot steam stress with a testing device developed in our institute. In a first series, textile samples are exposed to three conditions of hot steam jet (leading to three rates of heat flux: 4.31, 3.39, and 2.80 $W.cm^{-2}$) and to a hot saturated environment (80°C and 100% of relative humidity leading to a heat flux of 0.70 $W.cm^{-2}$). In a second series, protective garments are tested in a hot saturated environment (80°C and 100% of relative humidity) on a thermal manikin.
With the same thickness or inferior one, the textile samples and garments impermeable to water vapour are more efficient to limit the heat transfer due to hot steam stress exposure than the permeable ones. Moreover, thicker is the sample or the garment, higher is the thermal protection it gives. But, there is a maximal thickness over which the gain of protection is not enough sufficient to justify the increase of thickness. The diffusion of the water vapour through the textile samples and its absorption bring additional heat and decrease the protective capacities of the textile fabrics. This mechanism is observed with the permeable samples at the beginning of the exposure to hot steam jets and should be take into account to evaluate the samples or the garments to avoid skin burn. This mechanism is also observed with one impermeable sample after a time delay of exposure (depending on the steam conditions and the textile) probably due to a denaturation of the impermeability of the sample.
In conclusion, the best protection against hot water steam stress should be given by a thick, multi-layered and impermeable to water vapour garment with a wide cut to limit the contact with the skin.

Introduction
Accidental exposure to hot water steam is a potential hazard in the French Navy and particularly on nuclear submarines or ships. Exposure to hot steam atmosphere leads to severe and sometimes letal injuries in respiratory airways (Hathaway et al., 1996; Moritz et al., 1945) or in skin (Still et al., 2001).
In order to protect the submarine crew members of the French Navy, a study is carried out on protective capacities of textiles and equipments under hot steam stresses. A « steam laboratory » was created at the Institut de Médecine Navale du Service de Santé des Armées. A set of tools was developped: (i) a testing device for textile samples evaluation, (ii) a thermal manikin and a climatic chamber for clothings and procedures evaluation under steam stresses.

Materials and methods
Serie 1.
The device for textile sample evaluation can be used under two configurations: steam jet or steam atmosphere. It is composed of a steam generator (Sano clav Wolf, Bioblock, France), a sample support, a measuring cell (composed with a heat flux sensor, Episensor 025, JBMEurope, France) in which water circulates at a regulated temperature of 33°C, and a data logger (DaqBook 216, IOtech, USA) and a computer that allows to observe and save the measures (software: Daqview 7.1, IOtech, USA). Under steam jet configuration, the sample support and the measuring cell are fixed on a moving base. Under steam atmosphere configuration, this moving base is replaced by an isolated box in which steam atmosphere is created. In this configuration, the steam injection is made by an electrovalve asserved to a thermal regulator which regulates the box temperature at 80°C.

Paper presented at the RTO HFM Symposium on "Blowing Hot and Cold: Protecting Against Climatic Extremes", held in Dresden, Germany, 8-10 October 2001, and published in RTO-MP-076.

Table 1 shows the caracteristics of the basal samples which are presented in this paper.
The protocol is the same for all the conditions and corresponds to 10-min exposure to steam stress: the 3 jet conditions (J5, J10 and J15) depending on the distance between the steam output of the generator and the external side of the samples (respectively 5, 10 and 15 cm) and the atmosphere condition (ATM). The reference tests (REF) correspond to the measuring cell directly exposed to the steam stresses (4.312 ± 0.026, 3.394 ± 0.039, 2.804 ± 0.033 and 0.702 ± 0.117 $W.cm^{-2}$ for respectively J5, J10, J15 and ATM). Each test (REF or samples) is repeated 3 times.
The heat flux is measured every second throughout the exposure. The following variables are calculated with the heat flux values. SMF (Steam Mean Flux, $W.cm^{-2}$) corresponds to the average of the heat flux of 3 tests over the last minute of the exposure. AHT (total Amount of Heat Transfered, $J.cm^{-2}$) corresponds to the cumul of the heat transfered to the cell over the 10-min exposure. PR (Percent of REF, %) corresponds to the ratio between the SMF of the sample and those of the corresponding REF.
The results for three textiles samples, described in Table 1, are presented in this paper.

	Thickness (mm)	$\mathbf{R_T}$ ($m^2.K.W^{-1}$)	$\mathbf{R_e}$ ($m^2.Pa.W^{-1}$)
TC	0.50	0.0252	4.3
TX	0.40	0.0121	398
TLD	0.25	0.0198	10000

TABLE 1: Caracteristics of the samples. R_T: thermal resistance. R_e: evaporative resistance (EN 31092).

Serie 2.
Five protective equipments are evaluated on a copper thermal manikin in a 80°C saturated environment. The thermal manikin is divided in nine separate segments. The surface temperature is regulated at 33°C by water circulating inside copper pipes which are distributed on the internal face of the sheets (regulated surface: 1.349 m^2). The water flows are measured (Mc Milan Co, USA) and regulated at the output of each segment between 0.06 to 1.00 $l.m^{-1}$ (± 5%). Thus, total and local heat fluxes are calculated from temperatures and water flows. The REF test correspond to the nude manikin exposed to the climatic conditions. During the equipment tests, the thermal manikin is worn with the equipment and placed in the center of the chamber. For all the tests, the climatic conditions are 80°C of air temperature with step increase of humidity to the maximum allowed by the equipment. Due to high level of condensation on the regulated surface of the manikin, the chamber cannot reach saturation when the manikin is in. Thus, humidity is increase by step to the maximum the chamber can reach. And the heat flux value at saturation is extrapolated by exponential regression. For each step, the mean temperature of the surface of each segment of the manikin is regulated at 33°C. Temperatures and water flows are measured for each step over 7 minutes. Local and total heat fluxes are then calculated for each step. And the heat fluxes for saturation are calculated by extrapolation. The equipments are classified depending on their heat fluxes.
We present the results for five garments: TLD, TC, TBoy, TVTN and TMat. TLD and TBoy are water vapour impermeable garments. TC, TVTN and TMat are water vapour permeable ones. TC, TVTN and TLD are thin garments, while TBoy and TMat are thick ones. All these garments cover all the manikin surface except the head. The comparison between garments is made with the heat fluxes measured on the surface covered.

Results

Serie 1.
The Figure 1 shows some typical exemples of heat flux pattern during the 10-min exposure to the J10 condition. During REF tests (curve 1), the heat flux increases rapidely (in 2 to 3 sec) to a steam steady state (SMF = 3.394 ± 0.039 $W.cm^{-2}$). During TC tests (curve 2), there is a peak of the heat flux at the beginning of exposure. Then after, heat flux decreases to finally stabilise at a new level maintened till the end of the exposure (SMF = 1.606 ± 0.031 $W.cm^{-2}$). During TX tests (curve 3), the heat flux reaches rapidely a first steam steady state. But, after about 140 sec, the flux increases again till the end of exposure. During TLD tests (curve 4), the heat flux reaches rapidely the steam steady state (SMF = 0.808 ± 0.024 $W.cm^{-2}$).

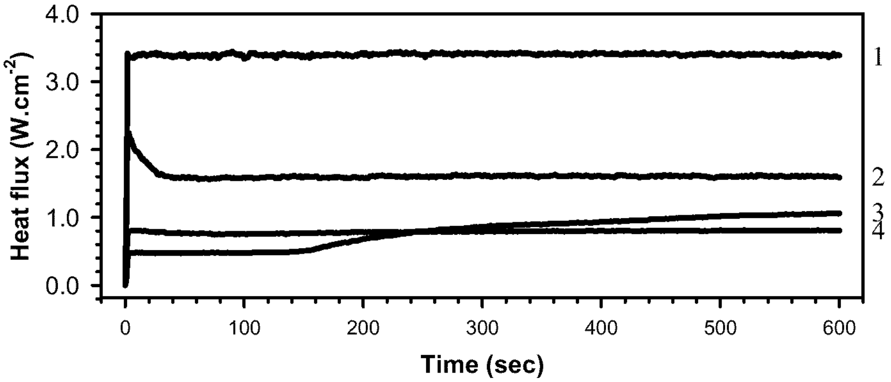

FIGURE 1 : Typical patterns of heat flux observed during the 10-min exposure to J10 condition (see text).

Figure 2 shows the impact of two ways of impermeabilization of a textile sample (TC) on the heat flux pattern during J10 condition. The impermeabilization is made either in adding a polyethylene foil of 10 µm thickness (P) ahead of TC (P+TC) and behind TC (TC+P) or in soaking TC just before the tests (TCm). When P is placed ahead of TC (P+TC), the pattern is typically those of an impermeable fabrics. But, when P is placed behind of TC (TC+P), the pattern is the same as TC alone but the peak is significantly decreased and SMF is lower. When TC is soaked before the tests (TCm), the peak is also significantly decreased and SMF is the same as TC.

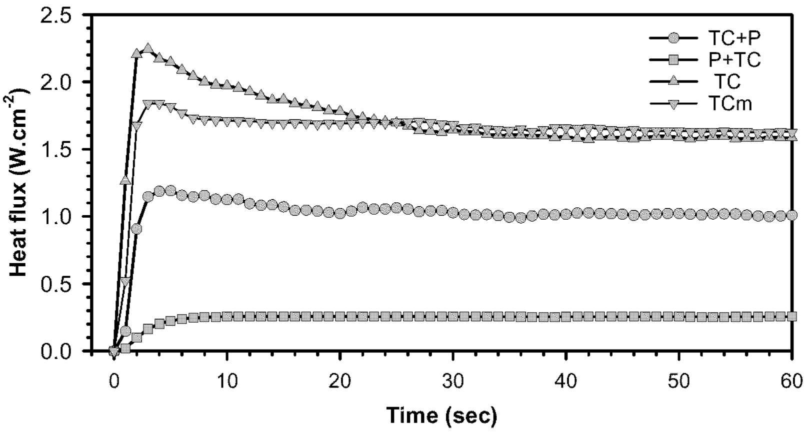

FIGURE 2: Heat flux of samples composed with TC during the first minute of exposure to J10 condition.

Table 2 shows the main results observed in condition J10 when the air layer behind the fabrics (TC and TLD) is increased artificially in adding one (3D4) or two layers (3D8) of a 3D polyethylene waffle fabrics of 4 mm thickness. Increasing the thickness of the air layer behind fabrics leads to lower SMF, AHT and PR, whatever the permeability of the fabrics. For the same thickness or a lower one, the impermeable fabrics leads to lower levels.

Sample	**SMF** (W.cm^{-2})		**AHT** (J.cm^{-2})		**PR** (%)	
REF	3.394	(0.039)	2038.2	(26.4)	-	
TC	1.606	(0.031)	968.8	(6.2)	46.5	(1.3)
TC+3D4	0.591	(0.017)	381.5	(7.1)	17.4	(0.7)
TC+3D8	0.388	(0.005)	249.9	(4.3)	11.8	(0.3)
TLD	0.808	(0.024)	473.3	(22.0)	23.7	(1.0)
TLD+3D4	0.069	(0.001)	41.3	(1.2)	2.0	(0.0)
TLD+3D8	0.042	(0.000)	24.6	(0.0)	1.3	(0.0)

TABLE 2: Main results observed in increasing the thickness of the air layer behind fabrics in condition J10.

SMF: steam mean heat flux. AHT: amount of heat transferred to cell in 10 minutes. PR: percent of the REF heat flux transferred.

Figure 3 shows the pattern of the heat flux observed with TX during the 3 conditions of steam jet. After a first increase at the beginning of exposure to steam, the heat flux increases again after a delay of steady state. The delay before increase and the range of increase depend on the condition.

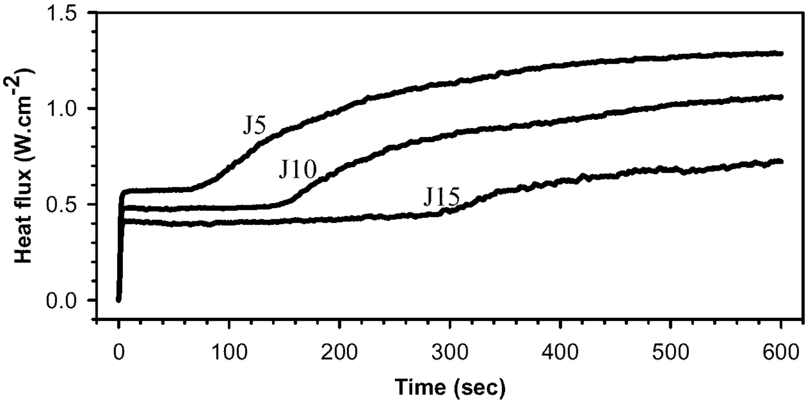

FIGURE 3: Heat flux observed with TX during the 3 conditions of steam jets.

Serie 2.

Figure 4 shows the local and total ratios between the mean heat flux of the samples and these of the REF test (PR, %). In a general way, results observed on garments and fabrics have the same meaning. The permeable garments to water vapour TC and TVTN lead to higher levels of heat flux and PR, since these 2 garments are thin. But TMat lead to about the same level of PR than TLD due to the higher thickness of the textile fabrics, composed with different textile layers. The best protection is brought by TBoy, TLD and TMat, and the lowest one by TC. The figure shows also that there is a higher difference between the local ratios with permeable garments, and specially between limbs and the others body segments.

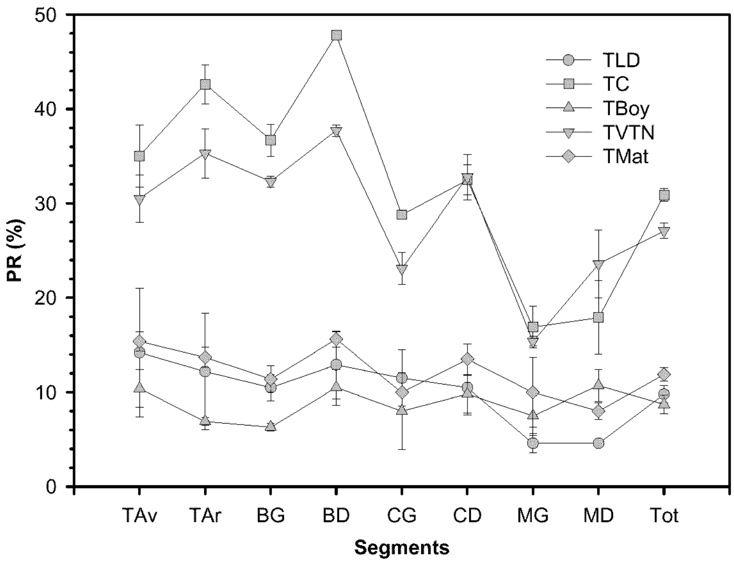

FIGURE 4: Ratio between the heat flux of the garments and those of the REF. TAv: front of the trunk, TAr: back, BG and BD: left and right arms, CG and CD: left and right thighs, MG and MD: left and right legs, Tot: total.

Discussion

In a general manner, the tests on textile fabrics and on garments are in good agreement. With the same thickness or inferior one, the textile samples impermeable to hot water steam are more efficient to limit heat transfer due to exposure to hot water steam than the permeable ones. At the beginning of the steam jet exposure, the permeable samples show a peak of the heat flux measured probably due to complex

phenomenons of condensation, diffusion and absorption of water inside sample releasing high level of heat (Farnworth, 1986; Lotens and Havenith, 1994). The « impermeabilisation » of permeable sample leads to the loss of these phenomenons. These phenomenons should also explain the results observed with TX (impermeable sample). After a delay of steam jet exposure, the sample seems to change its characteristics, and progressively becoming permeable. In this case, while the denaturation is not instantaneous, no peak of heat flux is observed but rather a regular increase depending on the denaturation rapidity. The rapidity depends on the level of steam agression. The denaturation is reversible for this sample. The maintenance of the properties of the textile samples should be evaluated under steam aggression to avoid skin injuries.
Moreover, thicker is the sample, higher is the thermal protection it gives. But, it seems to exist a maximal thickness over which the gain of protection is not enough sufficient to justify the supplementary increase of thickness.
In the same way, impermeable garments are more efficient to protect under steam stress. Furthermore, a loose-fitting cut (with a thick air layer between the garment and the skin) allows to increase the level of thermal protection of a thin garment. The ergonomic consequences of this kind of protection for human tolerance to work are to be evaluated.

Conclusions
The best protection against hot water steam aggression should be given by a thick, multi-layered and impermeable to water vapour garment with a wide cut to limit touches with skin. Moreover, the equipment should covered all the body surface to protect the skin surface and also the respiratory airways and the eyes. In these conditions, this protective garment should not be worn continually. The study should be continue to find a solution to protect the submarine crew members during their daily work.

References

Farworth B. A numerical model of the combined diffusion of heat and water vapor through clothing. Textile Research Journal, 1986, 56: 653-665.

Hathaway PB, Stern EJ, Harruff RC, Heimbach DM. Steam inhalation causing delayed airway occlusion. AJR, 1996, 166: 322.

Lotens WA, Havenith G. Effects of moisture absorption in clothing on the human heat balance. Ergonomics, 1994, 38(6): 1092-1113.

Moritz AR, Henriques FC, McLean R. The effects of inhaled heat on the air passages and lungs. An experimental investigation. The American Journal of Pathology, 1945, 21: 311-331.

Still J, Friedman B, Law E, Orlet H, Craft-Coffman B. Burns due to exposure to steam. Burns, 2001, 27: 379-381.